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Elasticity in ecosystem services: exploring the variable relationship between ecosystems and human well-being

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ABSTRACT. Although ecosystem services are increasingly recognized as benefits people obtain from nature, we still have a poor understanding of how they actually enhance multidimensional human well-being, and how well-being is affected by ecosystem change. We develop a concept of “ecosystem service elasticity” (ES elasticity) that describes the sensitivity of human well-being to changes in ecosystems. ES Elasticity is a result of complex social and ecological dynamics and is context dependent, individually variable, and likely to demonstrate nonlinear dynamics such as thresholds and hysteresis. We present a conceptual framework that unpacks the chain of causality from ecosystem stocks through flows, goods, value, and shares to contribute to the well-being of different people. This framework builds on previous conceptualizations, but places multidimensional well-being of different people as the final element. This ultimately disaggregated approach emphasizes how different people access benefits and how benefits match their needs or aspirations.

Applying this framework to case studies of individual coastal ecosystem services in East Africa illustrates a wide range of social and ecological factors that can affect ES elasticity. For example, food web and habitat dynamics affect the sensitivity of different fisheries ecosystem services to ecological change. Meanwhile high cultural significance, or lack of alternatives enhance ES elasticity, while social mechanisms that prevent access can reduce elasticity.

Mapping out how chains are interlinked illustrates how different types of value and the well-being of different people are linked to each other and to common ecological stocks. We suggest that examining chains for individual ecosystem services can suggest potential interventions aimed at poverty alleviation and sustainable ecosystems while mapping out of interlinkages between chains can help to identify possible ecosystem service trade-offs and winners and losers. We discuss conceptual and practical challenges of applying such a framework and conclude on its utility as a heuristic for structuring interdisciplinary analysis of ecosystem services and human well-being.

Key Words: *coastal ecosystems; conceptual framework; East Africa; environmentalists; fisheries; mangroves; paradox;*

INTRODUCTION

The Millennium Ecosystem Assessment (MA) conceptualized ecosystem services as contributions from nature to human well-being and drew on the “capability approach” proposed by scholars such as Amartya Sen (MA 2003, Robeyns 2005). This provided a broad conceptualization of well-being, including security, material assets, health, social relations, and freedom. In their recent review of well-being frameworks, Agarwala et al. (2014) describe how, in the context of ecosystem services, interest in the concept of multidimensional well-being evolved in response to limited mono-dimensional assessments, which were largely monetary and value-based. They argue that this is analogous to the development of a multidimensional understanding of poverty (Alkire 2007), which represents the opposite to well-being. They also acknowledge the challenge of engaging with such a more

complex vision of people’s lives. The concept of well-being is becoming increasingly central to research and policy on ecosystem services, and sustainability in general (Bizikova 2011). As Milner-Gulland et al. (2014) posit, engaging with human well-being may enable better outcomes for nature conservation by taking account of a broader spectrum of gains and losses as well as greater incorporation of people’s views and needs. Although many different frameworks exist for the study of well-being (e.g., OECD 2011, Oxfam 2013), there seems to be consensus that any measure of well-being should include both an objective measure of a person’s welfare, alongside a subjective evaluation of how a person thinks and feels about the quality of life they are experiencing (Gough and McGregor 2007, UN 2012). This clearly calls for integrative approaches combining quantitative and qualitative data (McGregor et al. 2015). Despite this interest and

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conceptual progress, significant gaps remain in our understanding of how ecosystems actually contribute to different people's well-being (Butler and Oluoch-Kosura 2006, Carpenter et al. 2009) and to alleviation of multidimensional and dynamic poverty (Alkire 2007). This lack of understanding has particular implications for poor people who are often more reliant on ecosystems for their food, physical security, and livelihoods (Duraiappah 2004, Bizikova 2011) and disproportionately affected by changes in ecosystem services.

The ecosystem service concept alludes to a positive relationship between ecosystem quality and human well-being^[1]. However, this relationship is complex and often indirect with the result that the well-being of people in particular places and times can be more or less coupled to ecosystem quality. For example, although it is clear at the aggregate global scale and in the long run, that humanity depends on the biosphere for survival (Dasgupta 2001), aggregate indicators of human well-being at the global scale appear to show that well-being has improved over recent years despite the ongoing degradation of ecosystems, a phenomenon referred to as the "environmentalist's paradox" (Raudsepp-Hearne et al. 2010). At smaller scales, people may experience improvements in well-being in the face of ecosystem degradation, when this enhances the opportunities for human development (e.g., Wunder 2001). Conversely, conservation may enhance ecosystems with little benefit, or even harm to the well-being of local people, for example by exclusion from reserves (Dowie 2011, Kamat 2014) or where "ecosystem disservices" such as crop raiding by wild animals impact local farmers (Woodroffe et al. 2005). Such examples of a negative relationship between ecosystem health and human well-being may represent temporal or spatial effects, either that degradation will impact the well-being of people in the future, or in other places, or that benefits from ecological enhancement take time to materialize or are enjoyed by distant beneficiaries. However, what these examples demonstrate is that in particular places and times, and for particular people, the relationship between ecosystem quality and human well-being is variable and complex.

We can refer to the human-well-being impacts of ecological change using the concept of "elasticity," which captures the responsiveness of one variable to changes in another (York et al. 2003). For example, in economics, the price elasticity of demand captures how much demand will change in response to a change in price. Here we apply the concept of elasticity to ecosystem services and explore the elasticity of human well-being to ecosystem change (henceforth "ES elasticity"), i.e., how human well-being changes in response to increases or declines in ecosystem quality. We propose that studying ES elasticity challenges us to engage with the complexities and context dependency of the ecosystem-well-being relationship, and can facilitate a better understanding of the role of ecosystem services in human well-being.

INTRODUCING ES ELASTICITY

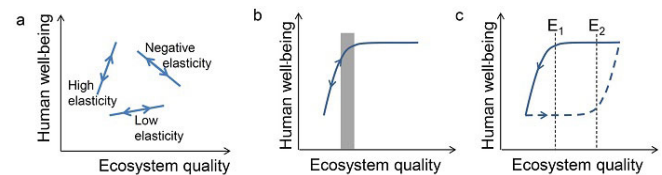
Elasticity describes how one variable changes in relation to changes in another, and thus ES elasticity can be formally represented as the following:

ES Elasticity = change in well-being / change in ecosystem stocks

Thus high, positive elasticity means that human well-being is strongly coupled to changes in ecosystem quality and people strongly benefit when ecosystem quality improves and suffer when quality declines. Examples of high, positive elasticity include when

the loss of storm protection services from mangroves severely impacts coastal people's security (e.g., Das and Vincent 2009), or when successful conservation of charismatic species promotes the livelihoods of tour guides. Meanwhile, low elasticity means that changing ecosystem quality has minor or negligible impacts on well-being, for example, when people are decoupled from the ecosystem because of alternatives or substitutes. Negative ES elasticity describes situations, like the environmentalist's paradox, in which people's well-being actually improves as ecosystem quality declines or people suffer as ecosystem quality improves (Fig. 1a). For the rest of this paper we use the term "high ES elasticity" to refer to high positive ES elasticity.

Fig. 1. The ecosystem quality elasticity of human well-being (ES elasticity). (a) Examples of high, low, positive, and negative elasticities. (b) A threshold (shaded) in the ecosystem quality-well-being relationship leading to different elasticities at different levels of ecosystem quality. (c) Hysteresis in the ecosystem quality-well-being relationship such that elasticity is different when ecosystem quality is declining from when ecosystem quality is increasing.



ES Elasticity will vary depending on the nature of the ecosystem-well-being link such that explaining or even forecasting ES elasticity challenges us to better understand both ecological and social dimensions, and context of such linkages. Elasticity has important implications for environmental management and poverty alleviation. Prescriptions for community-based conservation presuppose a self-evident and universally experienced positive elasticity that creates the necessary incentives for conservation (Roe et al. 2012). However, this may overlook or underplay the importance of delayed effects, trade-offs, and social disparities in terms of who benefits. Where conservation efforts are characterized by low or negative ES elasticity for some people, they may resist or sabotage such efforts. An example is the widespread low compliance with fisheries regulations and marine protected areas in the tropics (Wood et al. 2008). Thus failure to recognize or address low or negative ES elasticity can ultimately lead to failures in conservation initiatives (McClanahan 1999, Pascual et al. 2014).

ES Elasticity is also core to understanding human vulnerability to environmental change and factors that are critical to adaptation. Low elasticity for example, would be desirable, for example, where climate change impacts degrade ecosystems, to minimize the harm experienced by people as a result of this degradation. Conversely, high elasticities would be desirable in situations of ecological rehabilitation and recovery, so that people benefit as much as possible from improving ecosystem services and are also incentivized to support continued rehabilitation.

Although ES elasticity is defined as the sign and slope of a linear relationship between ecosystem quality and human well-being

(Fig. 1a), there is little evidence to suggest that this relationship will be a straight line. Rather, research into social-ecological systems has shown nonlinear relationships and thresholds to be common (Liu et al. 2007, Barbier et al. 2008, Barrett and Constanas 2014). For example, people's well-being may be relatively unaffected by initial losses of ecosystem quality, but below a certain threshold, further degradation leads to the breakdown of critical functions impacting well-being. This results in a nonlinear relationship in which elasticity is low when ecosystem condition is good but increases sharply (steeper line) when ecosystem condition is below a certain threshold (Fig. 1b).

Hysteresis and path dependency are also common features of complex social-ecological systems (Scheffer et al. 2001). For example, Figure 1c could illustrate a situation in which well-being benefits from a cultural ecosystem service, which in turn depends on skills and other intellectual assets that are lost when ecosystem quality falls below some threshold level (E_1). Subsequent recovery of ecosystem quality would not contribute to improving well-being in the absence of these assets, which may only recover (if at all) at higher levels (E_2) of ecosystem quality. Thus the expectation of nonlinear changes in social-ecological systems emphasizes the importance of context and history. ES elasticity may depend not only on the current state of ecosystems but also recent history.

ES elasticity can be applied to different units of analysis and at different scales. The environmentalist's paradox has been investigated as an aggregate system-level attribute at a global scale, but given the importance of individual experiences and circumstances for the understanding of well-being (Coulthard et al. 2011), research will also be needed that can capture the differences between groups of people, based in terms of their relationship to, and dependence on, different processes or components of the ecosystem. For example, ES elasticity will be higher for people with ecosystem-based livelihoods than people not directly dependent on local ecosystems. These individual elasticities will be affected by the range of individual assets and the institutional arrangements that determine how individuals and groups benefit from nature (e.g., Leach et al. 1999, Ribot and Peluso 2003, Hicks and Cinner 2014). When there are improvements in ecological quality people endowed with "mechanisms of access" (Ribot and Peluso 2003) stand to benefit more than those denied access. Thus disaggregated analysis of ES elasticity is likely to show contrasting patterns for different groups of people. Such that high positive and negative ES elasticity may be found among different stakeholders within the same system creating trade-offs and dilemmas in policy choices.

Although much research has focused on factors affecting the supply of ecosystem services, less attention has been given to the demand side (Lele et al. 2013, García-Nieto et al. 2013). Elasticity will be affected by these contextual factors, such as the availability of and access to alternatives to ecosystem services, such as nonecosystem-based employment, imported foods, technological innovations, or nonecosystem based social practices, that may compensate for declines in local ecosystem services (MA 2003)^[2] and will reduce ES elasticity for people who have access to them. Additionally, many ecosystem services may only contribute to well-being under particular circumstances (Andersson et al. 2015). For example, wild foods may only be important during

times of food shortage, storm protection during storms, and cultural services in the context of a culture that regards them as significant. In such cases, ES elasticity would only be high when circumstances supporting the demand side of ecosystem services are present.

A CONCEPTUAL FRAMEWORK TO INTERROGATE ELASTICITY

The previous section highlighted that ES elasticity can be determined by a range of social, ecological, historical, or contextual factors. Thus advancing understanding of ES elasticity requires an interdisciplinary effort that integrates the strengths of existing literature on production, trade-offs, and valuation of ecosystem services and the growing literature on human well-being and its connection to natural resources. Taken alone, each of these branches of the ecosystem services literature is insufficient to explain ES elasticity because of a partial view over the ecosystem-well-being relationship. For example landscape-scale modeling of ecosystem services has led to an improved understanding of generation of different ecosystem services (e.g., Goldstein et al. 2012) but has generally not evaluated how these services actually contribute to people's well-being. Ecosystem service valuations based on aggregate measures of willingness-to-pay such as market prices, provide indications of the welfare value of ecosystem services, but are criticized for downplaying nonmonetary aspects of well-being, failing to disaggregate to reflect how benefits are distributed in society, and being based on market prices that are skewed to reflect preferences of the wealthy. Meanwhile frameworks for the study of well-being are now being applied to assess specific ecosystem service contributions to different aspects of life (e.g., Abunge et al. 2013), and the impacts of conservation (Milner-Gulland et al. 2014), but the majority of well-being research has limited appreciation for ecological dynamics and change. Meanwhile, studies that explicitly relate well-being to ecological change are often correlational and lack a specific theory of causation or experimental evidence of how particular ecosystem services actually contribute to well-being (e.g., McNally et al. 2011).

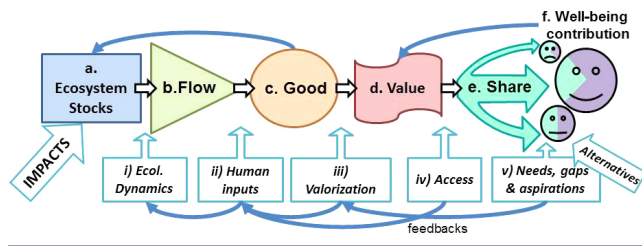
This section presents a conceptual framework that explicitly maps out the social and ecological links between ecosystems and well-being for different beneficiaries, and aims to understand how the well-being contribution of ecosystem services is shaped by people's individual condition and context over time. We acknowledge that a plethora of ecosystem service conceptual frameworks (e.g., Costanza et al. 2007, Bateman et al. 2011, Fisher et al. 2013, Reyers et al. 2013, Díaz et al. 2015) have been developed to facilitate thinking about the complex reality of ecosystem services. However, most frameworks generally have focused on specification of the ecological generation of ecosystem services to the detriment of understanding how they actually contribute to well-being (Fisher et al. 2013).

Our framework builds on the "cascade model" (Haines-Young and Potschin 2010), which was developed and adopted by TEEB (The Economics of Ecosystems and Biodiversity; Braat and de Groot 2012) and aims to conceptually clarify the steps by which ecosystems generate value. We augment this approach by returning to the MA's focus on multidimensional well-being rather than aggregate value as the end point. Thus we address some additional complexities highlighted by the more holistic model of

Fisher et al. (2014) but incorporate these into a more linear flow like the cascade, while maintaining an emphasis on the disaggregation of beneficiaries (Daw et al. 2011).

This framework shown in Figure 2 represents a chain of elements (a-f) that link from **Ecosystem Stocks** to **Well-being Contribution**. These are listed in Table 1. (For clarity, references to elements and multipliers are formatted as bold and italics, respectively). Each element has an influence on the next and the degree of this influence can be conceptualized as a component of ES elasticity. This breaks down overall ES elasticity between ecological stocks and well-being into subelasticities between each pair of elements. For example, elasticity of **Flow (b)** to **Ecosystem Stocks (a)** can be represented as the change in **Flows (b)** divided by change in **Ecosystem Stocks (a)**.

Fig. 2. A framework to interrogate ecosystem-well-being relationships and shed light on factors affecting ecosystem service elasticity. Ecosystem services are represented as a chain of elements (a-f) that link ecosystem stocks to well-being (See Table 1 for definitions, Table 2 for examples, and text for further elaboration).



$$E_{b,a} = \Delta b / \Delta a$$

and the product of the elasticities between elements ultimately determines how people's well-being is influenced by changes to **Ecosystem Stocks**, i.e., overall ES elasticity:

$$ES \text{ elasticity } (E_{f,a}) = E_{b,a} \times E_{c,b} \times E_{d,c} \times E_{e,d} \times E_{f,e} = \Delta f / \Delta a$$

This explicitly acknowledges that ES elasticity can be affected by any of the biophysical or social processes along this chain.

Elasticity between the elements (a-f) is influenced by five "multipliers" (i-v) that represent the things that explain or parameterize the relationship between adjacent elements. For example **Flows (b)** interact with *Human Inputs (ii)* to determine the quantity of **Goods (c)**:

$$\text{Goods (c)} = f(\text{Flows [b]}, \text{Human inputs [ii]})$$

Thus the multipliers are critical for determining the elasticity between adjacent elements and together, the ES elasticity of the overall chain between **Ecosystem Stocks** and **Well-being Contribution**.

The framework follows the cascade and MA frameworks, with arrows and an implied causality running from left (ecology) to right (well-being). This reflects our focus on elasticity and how ecosystem change can affect well-being. However, as emphasized in more social-ecological conceptualizations of ecosystem services (e.g., Reyers et al. 2013), causal influences in the other direction ("feedbacks" in Fig. 2), are important for the development of ecosystem quality and human well-being over

Table 1. Explanations and examples for the elements and multipliers. For clarity, references to elements and multipliers are formatted as bold and italics, respectively. See Table 2 for examples.

Element or Multiplier	Explanation
<i>Impacts</i>	Internal or external factors affecting Ecosystem Stocks
a. Ecosystem Stocks	The condition, volume, or diversity of ecosystems, "natural capital," includes "supporting services"
<i>i. Ecological Dynamics</i>	Dynamics that determine the production of Flows from Stocks .
b. Flow	Biophysical processes potentially directly useful for humans
<i>ii. Human Inputs</i>	Human factors that combine with Flows to coproduce Goods
c. Good	Things and services directly experienced or used by, and valued by people
<i>iii. Valorization</i>	Processes that determine the societal value of Goods
d. Value	Aggregate worth of benefit from goods produced, regardless of distribution
<i>iv. Access</i>	Processes that determine who can access Goods and benefit from their value
e. Share	The amount of Value that each person/group actually benefits from
<i>v. Needs, Gaps, and Aspirations</i>	The contextually and personally determined needs and aspirations of a group/person that can be satisfied by ecosystem services
f. Well-being Contribution	The improvement in well-being experienced by a group/person as a result of their Share meeting their Needs

time. For example, extraction of **Goods** impacts **Ecosystem Stocks**, while *Valorization* incentivizes and thus drives *Human Inputs*.

Ecosystem Stocks (a) represent natural capital or ecological assets (Bateman et al. 2011), affected by a wide range of impacts that may be external to this particular chain, such as climate change-driven disturbance or infrastructure development, or that represent feedback from within the chain, such as extraction of **Goods**. Stocks could be represented by a single indicator of ecosystem quality, e.g., live coral cover, but it may be more appropriate to include a range of processes and interactions within **Stocks**. For example, supporting services that maintain structure and functionality of ecosystems (Mace et al. 2012) would be included within **Ecosystem Stocks** because they do not directly contribute to well-being.

Flows (b), the biophysical processes that are potentially directly useful for humans are equivalent to Mace et al.'s (2012) "final services." They are generated by, but are importantly distinct from Ecological Stocks (Vira and Adams 2009). The complex and multifaceted relationship between the two (Mace et al. 2012) is represented by the multiplier *Ecological Dynamics (i)*, which encompasses variable production functions or biodiversity-ecosystem service relationships (Mora et al. 2014).

Goods (c) are the things or experiences from ecosystems that are valued by people (Bateman et al. 2011). **Goods** are not solely

biophysical, but are coproduced from **Flows** by *Human Inputs* (ii) (Lele et al. 2013) such as labor, capital, or the presence of people to appreciate or benefit from them.

The **Value** (d) of **Goods** is an aggregate indication of the total value of benefits generated by an ecosystem service, as calculated by standard valuation, although it could also be calculated in nonmonetary terms. **Value** is determined by societal process of *Valorization* (iii), such as the structure of markets, or cultural norms (Bateman et al. 2011). As such, *Valorization* represents the demand side of ecosystem services at an aggregate level and the contextual conditions that lead **Goods** to be of more or less interest and/or use to society in general.

Ecological Stocks, Flows, Goods, and Value (a-d) generally reflect the cascade model used for ecosystem service valuation (de Groot et al. 2010, Bateman et al. 2011) and are aggregate quantities. In contrast to the cascade model, **Value** (an aggregate quality) is not the final outcome, but is further mediated by **Share** and **Well-being Contribution** that focus on who accesses **Value** and how it contributes to their well-being (Coulthard et al. 2011, Daw et al. 2011). Thus the aggregate processes of *Valorization* are distinguished from the disaggregated processes of *Access*, and *Needs, Gaps, and Aspirations* that determine the **Well-being Contribution** of ecosystem services for different kinds of people.

Valorization may in some cases reflect the *Needs, Gaps, and Aspirations* of the same local people who benefit from **Well-being Contribution**. For example, in an assessment of local cultural ecosystem services *Valorization* is linked to both *Access*, and *Needs, Gaps, and Aspiration* of the same local people benefiting from the cultural ecosystem service (see sense of place example in Table 2). In contrast, *Valorization* of traded ecosystem services reflects motivations and aspirations of a different and often distant group of people. For example the market price of aquarium fish is determined by the aspirations of distant consumers as well as the availability of substitutes from other regions or aquaculture. This case illustrates why, for a disaggregated analysis, *Valorization* is considered independently from the *Needs, Gaps, and Aspirations*, of local people.

Share (e) is an explicit expression of the absolute amounts of **Value** received by different people, and is determined by the *Access* (iv), which represents the assets, institutions, laws, social norms, and structures (such as class, gender, ethnicity) that give people the ability to benefit from ES (Leach et al. 1999, Ribot and Peluso 2003). *Access* reflects power dynamics, for example as people compete to capture **Shares** or when governance structures impose limits on *Access* to reduce impacts on **Ecosystem Stocks**.

Well-being Contribution (f), reflects how an ecosystem service actually translates into well-being outcomes for an individual or group of beneficiaries. **Well-being Contribution** incorporates an assessment of the well-being of different beneficiaries (size of the circles in Fig. 2) as well as the proportional contribution to well-being from ecosystem services. In this framework, well-being is portrayed as the combination of needs met (a quantitative measure of the extent to which an individual, within a household, is able to sufficiently meet a predetermined list of basic needs) and life satisfaction (the person's subjective evaluation of how they are doing); the latter is captured methodologically through life satisfaction scoring, and more in-depth interviews.

Assessment of a person's well-being, even combined with an assessment of **Shares** is not sufficient to evaluate how ecosystem services actually contribute to well-being. This requires understanding of the individual circumstances that mean that a **Share** translates into a **Well-being Contribution**. As emphasized by the capability approach of Sen and others, "different people need different amounts of and different kinds of goods to reach the same levels of well-being" (Robeyns 2005:97). Hence *Needs, Gaps, and Aspirations* (v) constitute the multiplier between **Share** and **Well-being Contribution** and aims to capture the individual circumstances that determine whether a **Share** contributes to well-being. *Needs, Gaps, and Aspirations* incorporates objective and subjective dimensions that are affected by internal factors, such as personal illness or disability and individual preferences, as well as external factors such as substitutes, e.g., imported food, and events, e.g., storms, that affect what an individual or group needs from ecosystems. *Needs, Gaps, and Aspirations* thus reflect the demand side of ecosystem services on a more individual basis than *Valorization*.

The distinction between *Access* and *Needs, Gaps, and Aspirations* are illustrated by comparing a rich person with *Access* to wild foods but who does not benefit because they have no *Need* for them to a poor person who has a *Gap* in their nutritional security, but lacks *Access* to wild foods and hence has no **Share**. In both cases, wild foods make a limited contribution to well-being, but this is due to *Needs, Gaps, and Aspirations* in one case and *Access* in the other. In this sense *Access* represents the ability of people to benefit from **Share**, whether or not that ability is realized, and echoes Sen's (2001) concept of capabilities as distinct from functionings. Where *Needs, Gaps, and Aspirations* are low, patterns of *Access* may not be obvious. However, if *Needs, Gaps, and Aspirations* increase, e.g., during a food shortage, patterns of *Access* may become more obvious as people struggle to benefit from the available **Value**.

EMPIRICAL APPLICATIONS OF THE CHAIN FRAMEWORK TO UNDERSTAND ELASTICITIES

We applied the chain framework to five different regulating, provisioning, and cultural coastal ecosystem services studied in East Africa by the SPACES (Sustainable Poverty Alleviation from Coastal Ecosystem Services, <http://www.espa-spaces.org>) project (Table 2, Figure 3, Box 1). The cases illustrate a range of biophysical and social factors that lead to high or low ES elasticity. Examples of low ES elasticity include shoreline protection from reefs where biophysical dynamics mean that wave attenuation is not sensitive in the short term to changes in ecological quality (low **Stock-Flow** elasticity). In the example of livelihoods for female traders, increasing **Value** of landed fish is unlikely to improve female traders' livelihood if they cannot access that fish due to competition with male traders with higher buying power (low **Value-Share** elasticity due to limited *Access*). The aquarium fishery provides examples of high ES elasticity deriving from ecological and social factors. Many aquarium fish species are dependent on temperature-sensitive corals and thus sensitive to impacts of coral bleaching (high **Stock-Flow** elasticity), while connection to global markets generate a high price for the fish (high **Goods-Value** elasticity). The shade from mangrove trees example suggests that gleaners would be sensitive to loss of mangrove trees (high **Share-Well-being Contribution** elasticity) because of their *Needs, Gaps, and Aspirations* for shade and a lack

Table 2. Five coastal ecosystem services from East Africa (see Box 1) mapped out using the chain framework, with examples of low and high ES elasticity deriving from different parts of each chain. Multipliers contributing to low or high overall ES elasticity are marked with †.

Ecosystem service	Overall Low ES Elasticity		Overall High ES Elasticity		
	Shoreline protection from coral reefs	Livelihood support for female traders	Aquarium trade	Shade from mangrove	Identity/Sense of place
<i>Impacts</i>	Climatic change, development	Exploitation pressure, alternative income	International markets, climate change	Development, alternative livelihoods	Globalization, development
a. Stocks	Abundance of eroding organisms	Fish biomass	Abundance of coral reef organisms	Mangrove structure	Abundance of coral reef fishes
	Carbonate producer abundance and composition	Habitat composition	Coral abundance and species composition	Mangrove biomass	Coral abundance and species composition
<i>i. Ecological Dynamics</i>	Bioerosion rates†	Habitat effects†	Coral growth†	Mangrove growth rates	Fish-habitat interactions
	Carbonate producer growth rates†	Determinants of productivity (temperature, food)†	Determinants of productivity (temperature, food)†	Mangrove competition	Reef fish production
b. Flows	Wave attenuation	Stock-recruitment relationships†	Organisms for collection	Amount and type of cover	Large, valuable fish for harvest
<i>ii. Human Inputs</i>	Shoreline property/ use for cultural or livelihood activities	Fishing effort (time of fishers)	Collection effort/gear used	Type of use	Engaging in fishing
	Fishing/transport in calm waters	Fishing vessels and gear	Knowledge	Frequency of use	Engaging in community activities (sea weed farming)
c. Goods	Protected property	Landings of fish	Coral for export	Shade	Seaweed farm
	Boat trips for fishing or transportation		Small fishes for export	Privacy	Large fish and octopus landings
<i>iii. Valorization</i>	Cost of artificial protection	Market connectivity	Market connectivity†	Availability of other forms of shade	Broad community engagement†
	Economic and social benefits of shoreline use	Fish price	Fish and coral price†	Time spent working in the sun	History of engagement†
d. Value	Property value	Consumption and demand patterns	Demand from importing countries†		Common culture, admiration for fishers†
	Value of secured property	Total landed value	Total exported value	Value of health benefits from sun protection	Collective identity and pride as a community with skilled fishers
	Value of maintained tourism and recreation	Total value added along the supply chain	Value added along the supply chain		Productive fishery, successfully engaging in community projects
<i>iv. Access</i>	What is required to own property on shoreline	Purchasing capital and transport†	Collecting expertise	Proximity to mangroves	Owning a fishing license and gear
	How can people access shoreline/lagoon	Gendered roles†	Relationships with exporters	Availability of other forms of shade	Belonging to local fishers organization
e. Share		Relationships with fishers and customers	Financial capital		Belonging to the community (heritage)
	Who uses the shoreline and for what	Value added captured by each value chain actor	Value added captured by each value chain actor	Individual frequency of use	Community status and recognition
<i>v. Needs, gaps, and aspirations</i>		Individual earnings	Individual earnings		
	How much do property owners want/need that property	Alternative sources of income	Alternative sources of income	Dependence on activities taking place on the beach†	Other home, i.e., migrants
	How important is beach access for those using it	Cultural affinity to livelihood	Number of dependents, e.g., children	Time spent in the sun†	Other occupation
f. Well-being Contribution		Number of dependents, e.g., children		Availability of other forms of shade†	Importance of relationships
	Increase in physical security	Contribution to household income	Contribution to household income	Health benefits of being in the shade	Improves subjective well-being through pride
	Support for livelihoods and culture		Improves subjective well-being (status/knowledge)	Improves subjective well-being	Improves relational WB through belonging

of alternative shade. Identity and sense of place of fishers would be sensitive to an inability to maintain catches of large fish because of *Valorization* by the community (high **Goods-Value** elasticity) particularly for fishers whose identity and standing within the community depends on fishing (*Access*) and who lack alternative sources of pride or respect (lack of alternatives leading to high **Share-Well-being Contribution** elasticity).

Fig. 3. Images representing the five ecosystem services in Table 2. (A) The wave attenuation provided by the coral reef offshore at Bamburi beach, Mombasa, provides calm waters and beachfront for recreation in the evenings. (B) Female fish traders buying fish from fishers in Kenya. (C) Colorful corals and associated fishes of high value in international aquaria trade. (D) People resting in the shade of a tree in Vamizi, Mozambique. (E) Fishermen bringing large reef fish ashore.



Box 1:

ES Elasticity in East African coastal ecosystem services

Shoreline protection service

Between three and four million people on the East African coast likely benefit from shoreline protection because of coral reefs (Ferrario et al. 2014). The degree of wave attenuation is affected by the height of the reef as well as the species composition and abundance of live coral, relative to the abundance of eroding organisms, such as parrotfishes or urchins (Perry et al. 2008). The balance between these determines if a reef grows or erodes such that impacts such as coral bleaching can result in reefs starting to erode away. Nevertheless, ES elasticity of shoreline protection is low in the short term (Sheppard et al. 2005) because a high proportion of wave energy is dissipated by historically accreted

reef (Ferrario et al. 2014), and because skeletons of complex corals remain after they have died. Over time coral skeletons do break down as a result of biological erosion or storms (Graham et al. 2007), leading to increased wave energy reaching the shore (Sheppard et al. 2005). ES elasticity would therefore be low at first, and increases in the elasticity may be avoided through management of bioeroding populations on the reef, or through natural recovery of corals.

Livelihood support for female traders

The roles of people in the coastal Kenyan fishery are highly gendered. Women do not participate in catching finfish and their primary role is buying, frying, and selling low-value fish to local consumers (Yang 2013, Matsue et al. 2014). In sites around Mombasa, competition between traders to access fish can be high, particularly when catches are low. Male traders, who tend to have greater capital and access to transport such as bicycles (Yang 2013) have priority access to larger and higher value species. Heavy fishing effort by illegal beach seines, although damaging to the ecosystem, generate high volumes of low-value fish (McClanahan et al. 2008), while protected areas, enforcement against illegal gears, and lower fishing effort increases catch rates, fish size, and individual fishers' revenues (McClanahan 2010). However, the gendered access conditions suggests that such ecological improvements might negatively impact the livelihoods of female traders because of lower total catches and a shift in catch composition to high-value species favored by male traders (Daw et al. 2015).

Shade from mangroves service

The way that mangroves are valued by people is influenced by culture, and the level of dependence on mangroves for livelihoods and well-being (James et al. 2013). Even within households, men and women value resources differently based on gendered resource use practices (UNEP-WCMC 2014). The apparently insignificant small stand of mangrove trees (low **Ecosystem Stock**) adjacent to Lalane village in northern Mozambique contributes to the well-being of certain groups. Women gleaners for example, spend many hours in the sun at low tide collecting shells. With little or no alternative shade in the vicinity, the mangroves improve gleaners' subjective well-being by providing a cool sanctuary from the heat, which increases enjoyment of the activity and improves social relations. Thus this service demonstrates a high ES elasticity despite the very limited **Ecosystem Stocks**; the removal of these trees would negatively impact on the well-being of gleaners because the shade they offer is accessible to gleaners (*Access*) and because of gleaners' need for, and lack of alternatives to (*Needs and Gaps*) the shade from these mangroves.

Aquarium trade:

The ornamental coral reef wildlife trade supports a multimillion dollar industry (Grey et al. 2005), and can provide significant levels of income to local fishers on coral reefs in developing countries (Máñez et al. 2014). Many of the finely branched coral species and coral dwelling fish prized by aquarium collectors are highly susceptible to coral bleaching and other stressors (Loya et al. 2001). Thus the aquarium trade demonstrates high ES elasticity; overcollection, or shifts in coral community composition due to bleaching can result in large reductions in provision of species to the aquarium trade (**Flows**) despite

Table 3. Implications of high and low ES elasticities for policy and environmental management. CBNRM, community-based natural resource management.

ES elasticity	Low (or negative) elasticity No alignment between social and environmental goals		High (positive) elasticity Social and environmental goals are aligned	
Ecological change	Increasing quality	Declining quality	Increasing quality	Declining quality
Implications for environmental management	Lack of incentives to support enhancement	Lack of incentives to be concerned with degradation	Good for ecosystem based poverty alleviation	Risk and vulnerability to ecological change
Possible policy responses	Intervene on multipliers to increase Well-being Contribution for target groups (<i>Valorization</i> and <i>Access</i>). Monitor <i>Human Inputs</i> and impacts.	Don't assume self interested management, e.g., CBNRM will succeed. External support for conservation. Separate policy responses required for environmental and social goals.	Analyze multipliers to ensure elasticity stays high for target groups (especially <i>Access</i>)	Address ecological impacts and/or change multipliers to reduce elasticity and protect people from impacts, e.g., intervene on needs. Support availability and access to substitutes for ecosystem services.

relatively small changes in overall ecosystem health (**Ecosystem Stocks**).

Identity

People often develop an identity associated with a place as a result of the activities and relationships that people engage with there (Stedman 2002). For example, the emergence of place-based identities may be associated with the benefits and activities that are realized from the presence or utilization of ecosystem services, such as fisheries goods or through the use of the environment for recreation (supported by the coastal protection service) or shelter (provided by mangroves). For example, individuals from a fishing community may strongly identify with the reputation of having skilled fishers, from a close and supportive community, who engage in successful community conservation initiatives, and boast a productive and reliable fishery. The identity in this case is based on the same **Ecosystem Stocks, Flows and Goods** as a fisheries livelihood service. But, identity is also dependent on specific attributes of the **Good**, i.e., consistently large landings, and gain meaning (*Valorization*) through a history of social or community engagement. Individuals who are fishers and who belong to the community have *Access* to this identity. How important fishing, community, and recognition is to them and the extent to which they feel a sense of identity or belonging to another social group (*Needs, Gaps, and Aspirations*) will determine how this pride, identity, and sense of belonging contributes to their subjective and relational well-being. Because of the dependence of this identity on environmental quality and social engagement, a drop in environmental quality or social participation can rapidly affect the validity of a person's place-based identity, suggesting a high ES elasticity.

The linear arrangement of this conceptual framework, draws specific attention to the connections and elasticity between ecosystems and human well-being. However it also risks a linear and isolated representation of different ecosystem services and blindness to complexity created by feedbacks and interactions between different ecosystem services as Norgaard (2010) warns. In reality ecosystem services are interlinked and bundled as shown

by Figure 3, which illustrates the differential impact of coral bleaching on different fisheries and how food fish landings generate different kinds of **Value** (income, food) and how different groups *Access* different **Shares** of that **Value** and benefit to different extents.

Mapping how different types of benefits accrue to different people in this way is essential for understanding linkages and trade-offs. For example an increase in the price of fish in Figure 4 would represent an increase in *Valorization* of fish for income but would also decrease *Access* of poor consumers to fish for food.

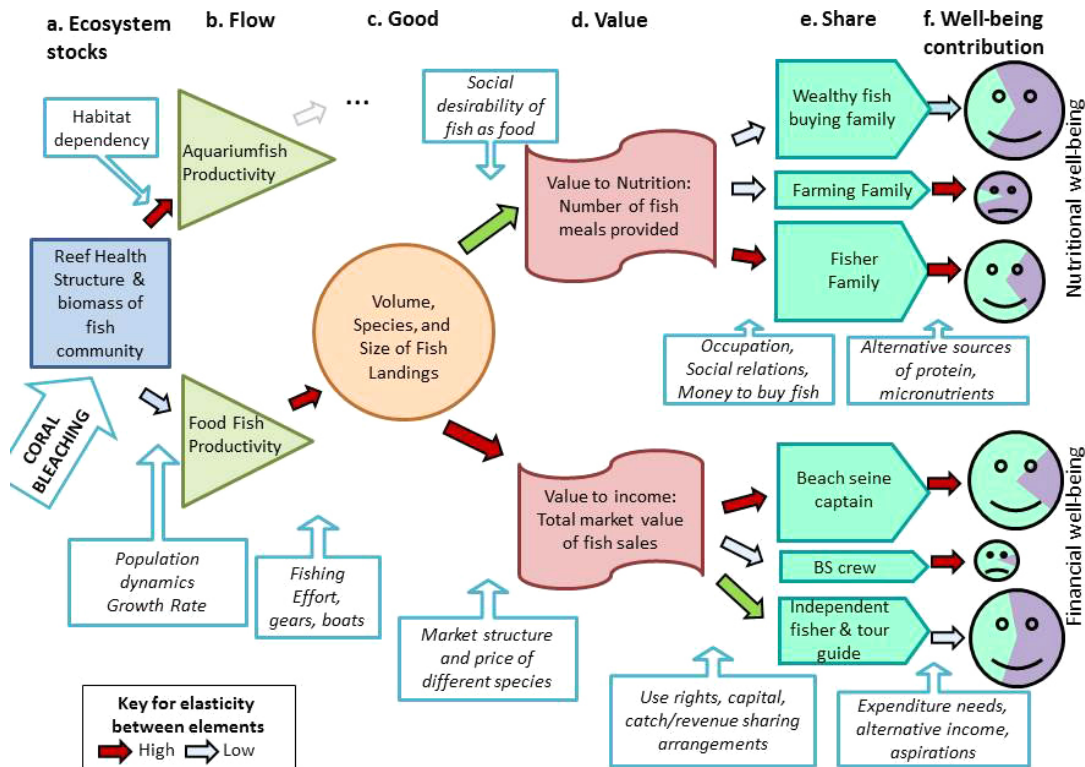
Multiplier effects in local economies may indirectly benefit multiple beneficiaries, such as tourism enhancing prices for local producers who can in turn hire more labor. In some cases such indirect benefits may be important for the well-being of many people (e.g., Ashley and Mitchell 2007) in which case they would need to be included in the aggregate calculation of **Value**. Value chain analysis can then identify how different people have *Access* to different shares of this **Value**.

POLICY RELEVANCE OF ANALYSING CHAINS AND ELASTICITY

We suggest ES elasticity can be applied to understanding vulnerability of different social actors to change in ecosystems, and to identify and assess the opportunities and potential interventions to improve well-being. The policy implications depend on the particular circumstance, specifically if the ES elasticity is high or low (or negative) and whether ecosystem quality is declining or improving (Table 3). Vulnerabilities of people result from high elasticities to ecological decline, or from processes that change multipliers and reduce elasticity, e.g., loss of access. Opportunities occur in situations of high elasticities when ecological enhancement is possible or where interventions can change multipliers to increase the **Well-being Contribution** of ecosystem services (Table 3).

First, the chain framework applied to any individual ecosystem service can identify important multipliers (and points of ES elasticity) as opportunities to reduce vulnerability or enhance or maintain the contribution of ecosystem services to well-being,

Fig. 4. The branching of an ecosystem services-well-being chain by consideration of multiple flows from a given stock, multiple values of a good, and multiple groups of people receiving different shares of that value that contributes to each's well-being dependent on their needs, gaps, and aspirations. The aquarium fish chain is only illustrated as far as the flow. Arrows between each element highlight high or low elasticity between elements along the chain.



and to evaluate the relative impact of interventions affecting different parts of the chain. The framework broadly suggests six different classes of interventions to increase well-being described and exemplified in Table 4.

Second, understanding the elasticities within different chains and distribution of benefits as illustrated in Figure 4 facilitates an assessment of trade-offs linked to different interventions. This information can be analyzed with decision makers, for example, through use of scenarios exercises or “toy models” and other interactive techniques (e.g., Daw et al. 2015), to discuss the trade-offs associated with different courses of action. This is particularly relevant to interventions such as Payments for Ecosystem Services, or Community-based Conservation, where simplistic assumptions about benefits and their distribution may lead to negative outcomes in terms of compliance and negate “success” in ecological and social terms (Pascual et al. 2014).

Application of this framework clearly poses challenges. The data requirements for populating the chains to analyze elasticities are considerable, requiring a coordinated interdisciplinary effort incorporating ecologists and a diversity of social scientists. In addition, practical application of the elasticity concept may be challenging in highly dynamic settings where elements and multipliers change very rapidly. In such circumstances, the framework may be best used as a frame to guide rapid, qualitative,

Table 4. Interventions to improve well-being suggested by the ecosystem-well-being chain conceptual framework.

Location on the ecosystem-well-being chain	Example
Reduce <i>Impacts</i> to improve or protect Stocks	Habitat restoration by replanting of cleared mangroves
Manipulate <i>Ecological Dynamics</i> to increase Flows	Semienclosed aquaculture to increase production of useful species
Facilitate <i>Human Inputs</i> to increase the production of Goods	Training or equipment to support exploitation of unexploited goods or services
Enhance <i>Valorization</i> to increase the Value	Value addition such as certification, marketing, or branding of fisheries products
Support <i>Access</i> for particular groups to increase their Share of benefits	Promote representation of marginalized groups, e.g., women, in resource management bodies
Directly meet people's <i>Needs, Gaps, and Aspirations</i> to reduce the Well-being Contribution so that they are less vulnerable to ecological change.	Provision of sanitation infrastructure so people do not depend on mangroves

and participatory diagnoses of ES elasticity and the resulting opportunities. An outstanding challenge remains in linking ecosystem quality and well-being at different scales. Although dependency and ES elasticity may be reduced at one scale, alternatives are frequently based on ES from further afield so that well-being is sensitive to aggregate **Ecological Stocks** and multipliers at larger scales beyond the scope of most place-based assessments.

Modeling, particularly recent innovation and development of “end-to-end” models (Fulton 2010), may provide an opportunity to synthesize diverse types of information (from biophysical to social), to explore how patterns of elasticity emerge and can be modified. Modeling approaches range from simple empirical relationships between **Ecosystem Stocks, Flows, and Goods** and some measure of well-being, to simulation models that have explicit representation of socioeconomic and ecological processes and their temporal and spatial dynamics. Existing modeling approaches mostly focus on the biophysical dynamics, with only simple representation of **Goods**, e.g., catches, and **Values**, e.g., net economic profits, and occasionally **Share** for different groups or sectors, e.g., along the value chain (Christensen et al. 2011). The subjective and context-dependent nature of well-being suggests that participatory modeling may provide a means to better represent the right-hand side of the chain from **Value** to **Well-being Contribution**. For example, to explore the trade-offs between different stakeholders under scenarios of fisheries management in coastal Mombasa, outputs from ecological models were linked to a rule-based model describing the interactions between different groups of fishers, fish traders, and their well-being (Daw et al. 2015). Other modeling approaches such as agent-based modeling (Murray-Rust et al. 2013) also offer potential for disaggregating individual **Shares** and **Well-being Contribution**.

CONCLUSION

Given the complex and as yet poorly understood linkages between ecosystem services and human well-being, ES elasticity is proposed as a core concept that informs these critical relationships. These relationships are expected to be nonlinear, complex, and context dependent.

Our heuristic framework of an ecosystem service chain is designed to help analysis of elasticities of different ecosystem services. This framework promotes and facilitates a structured assessment of ecosystem services-well-being relationships as a common starting point for interdisciplinary analysis and should provide important insights into trade-offs and possible policy levers. It can facilitate a pro-poor and well-being-explicit approach to understanding different mechanisms along the chain that determine who is able to derive what benefits from changes in ecosystems. This adds to existing ecosystem services frameworks that may overlook critical issues of access, needs, and aspirations or ecological dynamics. Applying this framework across different ecosystem services, contexts, and for different people to explore patterns of ES elasticity could advance both ecosystem services theory and provide practical guidelines for pursuing environmental management for human well-being.

[1] We acknowledge that “ecosystem quality” implies a value-laden assumption of quality that depends on what aspects of an

ecosystem are desirable (Robards et al. 2011). We do not discuss this in this paper and assume that some dimension of ecosystem quality is applicable in practise, as indicated by the frequent use of proxies such as indicators of forest cover, biodiversity, or fish biomass.

[2] In practise these substitutes are often also ecosystem services, e.g., imported food, from elsewhere but in many cases this represents a subsidy from ecosystems outside the scope of the system under study.

Responses to this article can be read online at:

<http://www.ecologyandsociety.org/issues/responses.php/8173>

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